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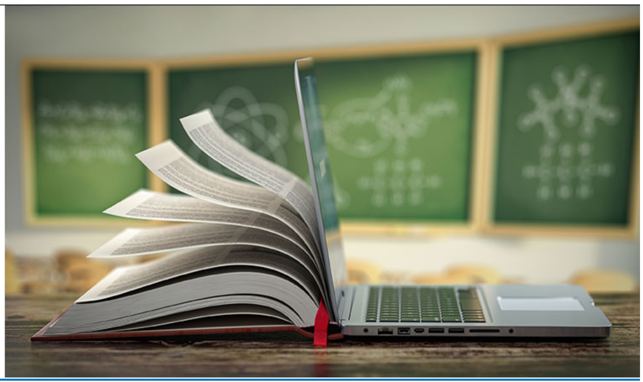

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The experimental data on the density, viscosity, and boiling temperature of the coffee extract

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Abstract. The paper shows the experimental data on the density, viscosity, and boiling temperature of the coffee extract. The mass fraction of the dry substances varies in the range of 15-70 % for all measurements. The coffee extract temperature varies in the rage of 20-80 °C for the density and viscosity measurements. It is found that the coffee extract density varies in the range of 1030-1350 kg/m^3 for the considered cases. The coffee extract viscosity varies in the range of 0.0008-27.4810 Pa·s for the considered cases. The coffee extract boiling temperature varies in the range of 100.0-103.3 °C at atmospheric pressure. It was found that the coffee extract is foaming in the considered range of dry substances mass fraction. The foaming temperature is decreasing with the dry substances mass fraction increasing.

1. Introduction

One of the main stages of soluble coffee production is the coffee extract drying [1, 2, 3, 4, 5]. The previous stage of soluble coffee production is the coffee extract evaporation [1, 3, 5]. The evaporation stage allows to reduce the energy consumption of soluble coffee production and to increase the product quality. It is important to know the physical properties of coffee extract for the extract evaporation equipment design. Also, it is necessary to know the coffee extract density and viscosity to drying equipment sprayer type choose. Thus, the obtaining of the experimental data on the coffee extract rheological and thermophysical properties is an important applied task.

One of the most significant thermophysical properties using in an evaporation equipment design and calculation is the boiling point dependence on the dry substances mass fraction. J. Telis-Romero and coworkers present experimental data on the coffee extract boiling point increasing (thermal depression) for the coffee extract with dry substances mass fraction in the range of 8.4-34.4% (9.2-52.4 °Brix) [6]. J. Telis-Romero and coworkers show that the coffee extract thermal depression for the pure water boiling temperature in the range of 32-92 °C is not more than 3.5 K [6]. In another work, J. Telis-Romero and coworkers present experimental data on the coffee extract density, specific heat, thermal conductivity, and thermal diffusivity for the dry substances mass fraction in the range of 10-50 % and the temperature in the range of 30-82 °C [7].

K. Burmester and coworkers provide experimental data on the density, viscosity, thermal conductivity, and thermal capacity of the coffee extract for the dry substances mass fraction in the range of 0-40 % and the temperature in the range of 20-60 °C [8]. Telis-Romero's and Burmester's experimental data on coffee extract thermophysical properties correspondent well.

J. Telis-Romero and coworkers show experimental data on the coffee extract viscosity for the dry substances mass fraction in the range of 10-51 % and the temperature in the range of 18-92 °C [9]. It is shown that the coffee extract has non-Newtonian rheology for the dry substances mass fraction of more than 36 % [9]. Telis-Romero's and Burmester's experimental data on coffee extract viscosity correspondent well.

2. Experimental materials, methods, and equipment

In our research, we measured the coffee extract density and viscosity for the dry substances mass fraction in the range of 15-70% and the temperature in the range of 20-80 °C. Also, we measured the coffee extract boiling temperature for the dry substances mass fraction in the range of 15-70% at atmospheric pressure.

The coffee extract boiling temperatures for the dry substances mass fraction in the range of 15-70% at atmospheric pressure were measured using the Swietoslawsky-type ebulliometer with the 0.1 °C value of the division thermometer. The error of the boiling temperature measurement was not more than 0.5%.

For the coffee extract density measurement, we used the set of aerometers with a measuring range of 1000-1300 kg/m3 for the extract with dry substances mass fraction less than 50%. For the density measuring of the extract with the dry substances mass fraction less more 50% we used the pycnometer method. The density measurement error was not more than 0.15% for extract with the dry substances mass fraction less than 50% and not more than 0.5% for the extract with the dry substances mass fraction more than 50%.

For the coffee extract viscosity measurement, we used the capillary viscometers with capillary diameters 0.99 and 1.47 mm for the extract with dry substances mass fraction less than 50%. The viscosity measurement error was not more than 0.5% for this range of the dry substances mass fraction. For the viscosity measuring of the extract with the dry substances mass fraction more than 50%, we used the capillary viscometers with capillary diameters 0.99 and 1.47 mm for the temperature 50 °C and more. For the temperatures less than 50 °C we used cup viscometer with the nozzle diameter 4 mm. The viscosity measurement error was not more than 2.5% for this range of the dry substances mass fraction.

The experimental measurement errors were calculated by Student's method [10]. The regressive equations were obtained by the method of least squares using the Scilab program package.

3. Results and discussion

Figure 1 shows the dependence of the measured coffee extract boiling temperature from the dry substances mass fraction at atmospheric pressure. The coffee extract boiling temperature increases nonlinearly with the dry substances mass fraction increasing. The boiling temperature changes slightly for the dry substances mass fraction in the range of 0.15-0.70. The maximum thermal depression is 3.2 °C and takes place for the dry substances mass fraction 0.7. Thus, the results of our measurements correspondent well with J. Telis-Romero's data [6].

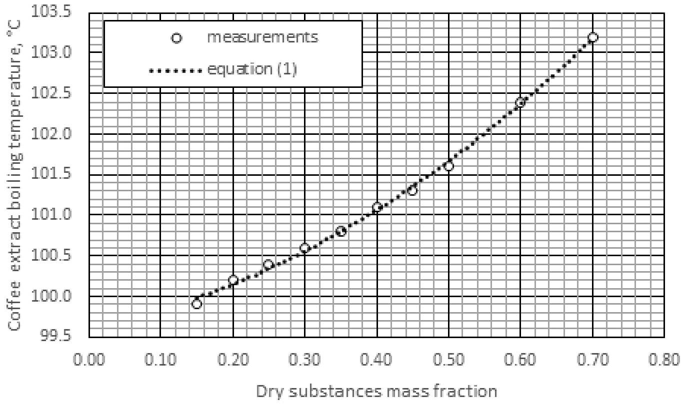

Figure 1. Dependence of the measured coffee extract boiling temperature from the dry substances mass fraction at atmospheric pressure.

The regressive equation of the dependence of the measured coffee extract boiling temperature from the dry substances mass fraction at atmospheric pressure takes the form:

$$T_b = 4.9395 \cdot f^2 + 1.6099 \cdot f + 99.633. \quad (1)$$

There T_b is the boiling temperature, °C; f is the dry substances mass fraction. The approximation error of the equation (1) is 0.26%.

Figure 2 shows the dependence of the measured coffee extract density from the dry substances mass fraction and the temperature. The density depends on the dry substances mass fraction and the temperature almost linearly both. For the dry substances mass fraction in the range of 0.15-0.70 and the temperature in the range of 20-70 °C the coffee extract density increases with the dry substances mass fraction growth and decreases with the temperature rising. The minimum and maximum values of the measured coffee extract density are 1030 kg/m^3 and 1350 kg/m^3, respectively. The results of our measurements correspondent well with J. Telis-Romero's [7] and Burmester's [8] data.

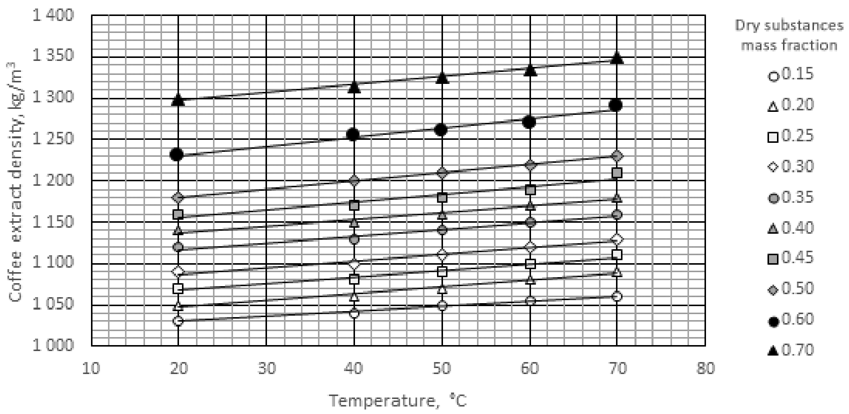

Figure 2. Dependence of the measured coffee extract density from the dry substances mass fraction and the temperature.

The regressive equation of the dependence of the measured coffee extract density from the dry substances mass fraction and the temperature takes the form:

$$\rho = 932 + 0.8 \cdot t + 509 \cdot f. \quad (2)$$

There ρ is the coffee extract density, kg/m^3; t is the temperature, °C; f is the dry substances mass fraction. The approximation error of the equation (2) is 1.97%.

Table 1 shows the measured values of the coffee extract kinematic viscosity for the dry substances mass fraction in the range of 0.15-0.70 and the temperature in the range of 20-70 °C. Figure 3 shows the dependence of the dynamic viscosity of the coffee extract from the dry substances mass fraction and the temperature.

Table 1. Measured values of the coffee extract kinematic viscosity.

Temperature,	Kinematic viscosity, mm^2/s, for the dry substances mass fraction									
°C	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.60	0.70
20	2.131	3.151	5.258	9.272	11.873	26.490	50.290	85.2	778.0	20417.0
40	1.333	1.990	3.053	4.919	7.378	11.805	25.339	35.3	325.0	2780.0
50	1.081	1.616	2.375	3.816	5.173	8.920	15.645	23.8	181.8	1343.0
60	0.969	1.374	1.951	2.967	4.240	6.911	11.325	16.5	109.7	683.2
70	0.858	1.141	1.640	2.431	3.336	5.375	7.774	12.3	72.1	360.7
80	0.747	0.989	1.357	2.148	2.742	4.127	5.759	8.8	50.5	291.2

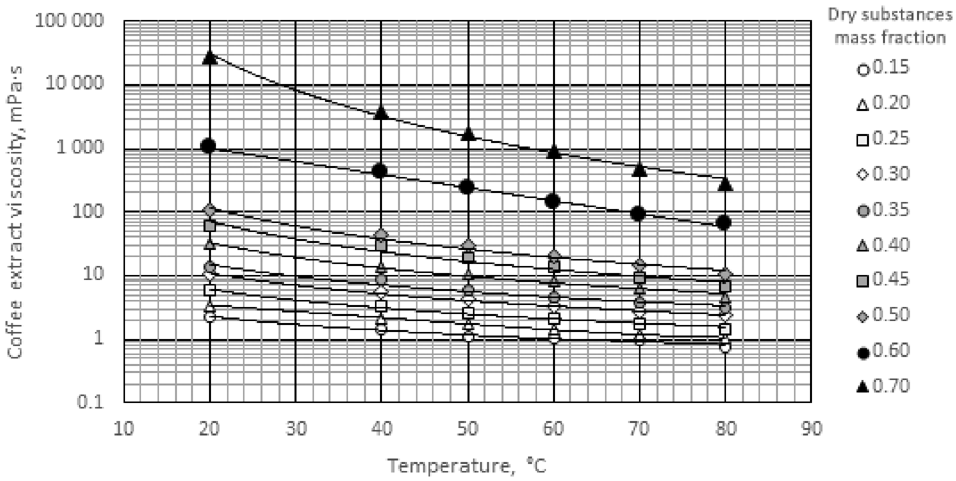

Figure 3. Dependence the dynamic viscosity of the coffee extract from the dry substances mass fraction and the temperature.

The dynamic viscosity values were obtained from the measured values of the coffee extract density and kinematic viscosity. The resulting error of the dynamic viscosity finding is 3.0%. The coffee extract viscosity decreases quickly with the temperature growth to 40 °C. For the temperature values of more than 40 °C the viscosity decreasing is slow. Also, it was found, that the coffee extract viscosity increases nonlinearly with dry substances mass fraction growth. For the dry substances mass fraction in the range of 0.15-0.70 and the temperature in the range of 20-80 °C the coffee extract viscosity minimum and maximum measured are 0.769 mPa·s and 27481 mPa·s, respectively.

The viscosity depends on temperature by the power law. The regressive equations of the dependences of the coffee extract viscosity from the temperature take the forms:

$$\mu = a\left(\frac{t}{100}\right)^{b}. \qquad (3)$$

There μ is the viscosity, mPa·s; *a* and *b* are regression coefficients; *t* is the temperature, °C. Table 2 shows the values of regression coefficients and the approximation errors of the coffee extract viscosity regressive equations for the dry substances mass fraction in the range of 0.15-0.70. The average approximation error of the coffee extract viscosity for the considered dry substances mass fraction is 8.2%. The maximum approximation error value is 26.1%. Thus, the calculated values of the coffee extract viscosity are rough. But obtained regressive equations may be used for the estimation calculations.

Table 2. Values of regression coefficients and the approximation errors of the coffee extract viscosity regressive equations.

Dry substances mass fraction	Regression coefficient a	b	Equation average approximation error
0.15	3.85	-0.741	4.0%
0.20	6.50	-0.851	4.8%
0.30	12.10	-0.984	4.6%
0.35	32.80	-1.090	4.1%
0.40	84.79	-1.084	8.6%
0.45	215.27	-1.335	5.6%
0.50	363.86	-1.590	13.8%
0.60	4931.00	-1.637	9.2%
0.70	300557.00	-2.004	16.2%

During the boiling temperature, density, and viscosity measurement, it was found that the coffee extract is foaming in the considered range of dry substances mass fraction. The foaming temperature is decreasing with the dry substances mass fraction increasing. For the dry substances mass fraction of 0.70 the foaming starts for the coffee extract temperature of 80 °C. For the dry substances mass fraction of 0.60 the foaming starts for the coffee extract temperature about 90-95 °C. For the coffee extract temperatures near the boiling temperature, the foaming significantly decreases. Also, it was found, that the stirring does not increase the foaming.

4. Conclusion

We have obtained the experimental data on the coffee extract boiling temperature at atmospheric pressure and on the coffee extract density and viscosity for the dry substances mass fraction in the range of 0.15-0.70 and the temperature in the range of 20-70 °C.

We found that the coffee extract boiling temperature changes slightly for the dry substances mass fraction in the range of 0.15-0.70 at atmospheric pressure. The maximum thermal depression is 3.2 °C in the considered range of the dry substances mass fraction.

It was shown that the coffee extract density increases with the dry substances mass fraction growth and decreases with the temperature rising. In the considered ranges of the temperature and dry substances mass fraction the minimum and maximum values of the measured coffee extract density are 1030 kg/m3 and 1350 kg/m3, respectively.

It was found that the coffee extract viscosity increases nonlinearly with dry substances mass fraction growth and depends on temperature by the power law. For the dry substances mass fraction in the range of 0.15-0.70 and the temperature in the range of 20-80 °C the coffee extract viscosity minimum and maximum measured are 0.769 mPa·s and 27481 mPa·s, respectively.

It was found that the coffee extract is foaming in the considered range of dry substances mass fraction. The foaming temperature is decreasing with the dry substances mass fraction increasing. For the temperatures close to the boiling temperature the foaming significantly decreases.

The regressive equations of the dependences of the coffee extract boiling temperature, density, and viscosity from the dry substances mass fraction and temperature were obtained.

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